Better Plants Online Learning Series

We'll be starting in just a few minutes….

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Online Learning Series – Webinar #12
Process Cooling Systems

Eli Levine

Office of Energy Efficiency and Renewable Energy

Eli Levine

U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY

Better Plants Online Learning Series

Webinar Topic	Speaker	Date	Time	Link
7. Energy Treasure Hunts with EPA	Alex Floyd (Tyson) Walt Brockway (ORNL) Walt Tunnessen (EPA)	08/20/20	1:00 – 2:00pm EST	Watch Recording
8. Pumps and Fans	Thomas Wenning (ORNL)	08/27/20	1:00 – 2:30pm EST	Watch Recording
9. Process Heating and Waste Heat Reduction	Sachin Nimbalkar (ORNL)	09/03/20	1:00 – 2:30pm EST	Watch Recording
~~10. Field Validation~~	~~Eli Levine (DOE)~~ ~~Paul Sheaffer (LBNL)~~	CANCELED	Rescheduled Date **TBD**	
11. Energy Management During a Pandemic	TBD	09/17/20	1:00 – 2:00pm EST	Watch Recording
12. MEASUR Tool Suite	Kristina Armstrong (ORNL)	09/24/20	1:00 – 2:00pm EST	
13. Process Cooling	Wei Guo (ORNL)	10/01/20	1:00 – 2:30pm EST	

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Dr. Wei Guo

Oak Ridge National Lab

U.S. DEPARTMENT OF ENERGY

Process Cooling Systems

Wei Guo, PhD, PE
Oak Ridge National Lab

–

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System Overview

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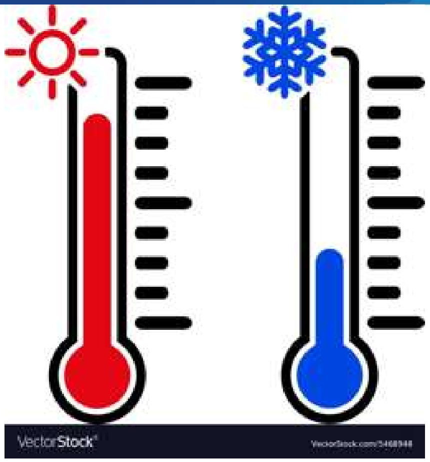
Purpose of Process Cooling Systems

- **Space temperature and humidity** control
  - Process
  - Comfort
- **Process temperature** control
  - Quenching processes
  - Chemical reactions
  - Process equipment cooling
- **De-humification**



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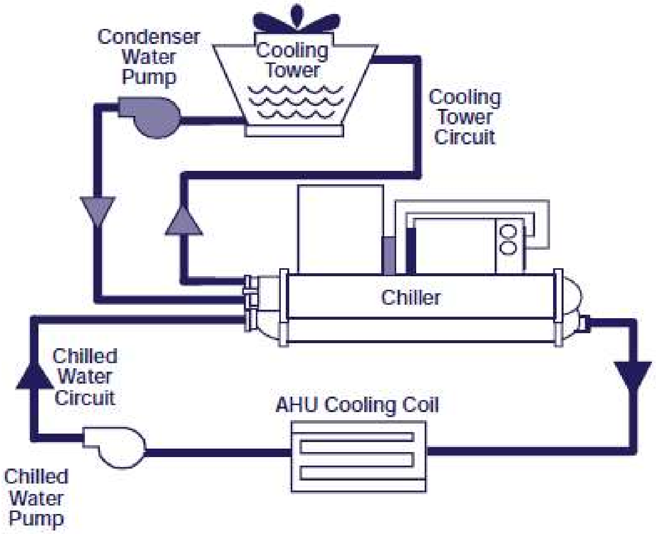
Why Do We Care?

- **Energy cost**
  - Cool and dry air and chilled water can be very expensive
- **Complexity**
  - Many components
- **Many opportunities**
  - Quick payback
  - Easy to replicate

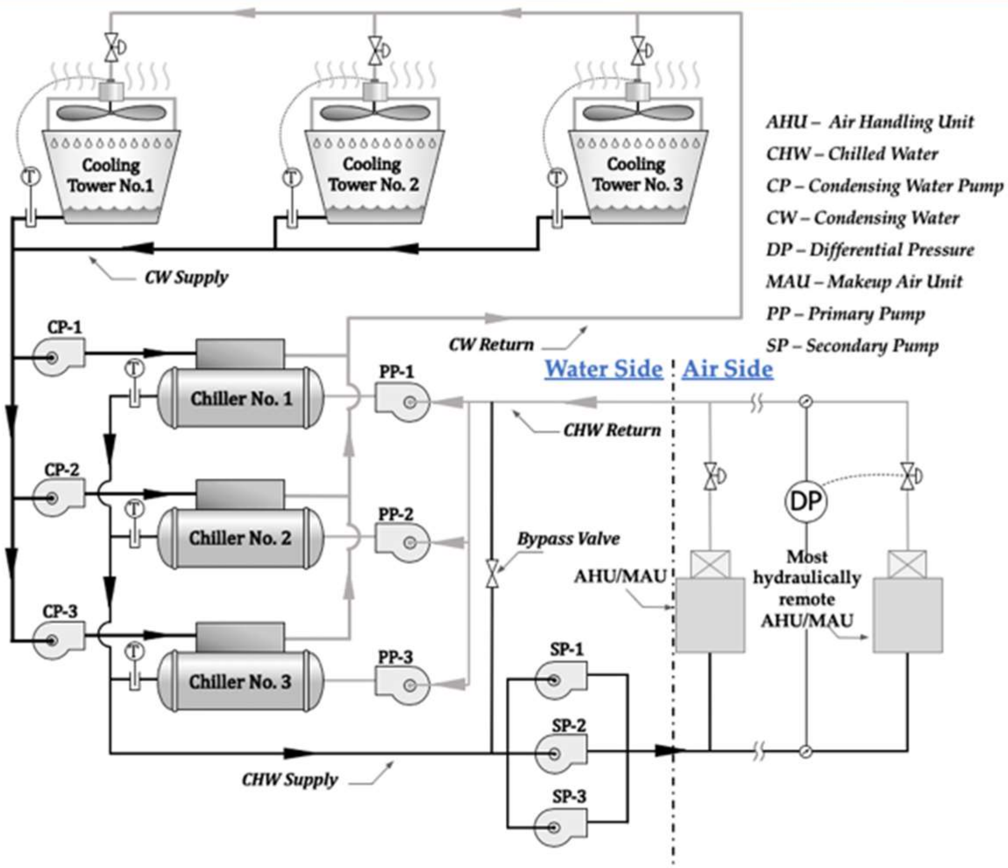
Source: Vyron



Source: www.chiller.com

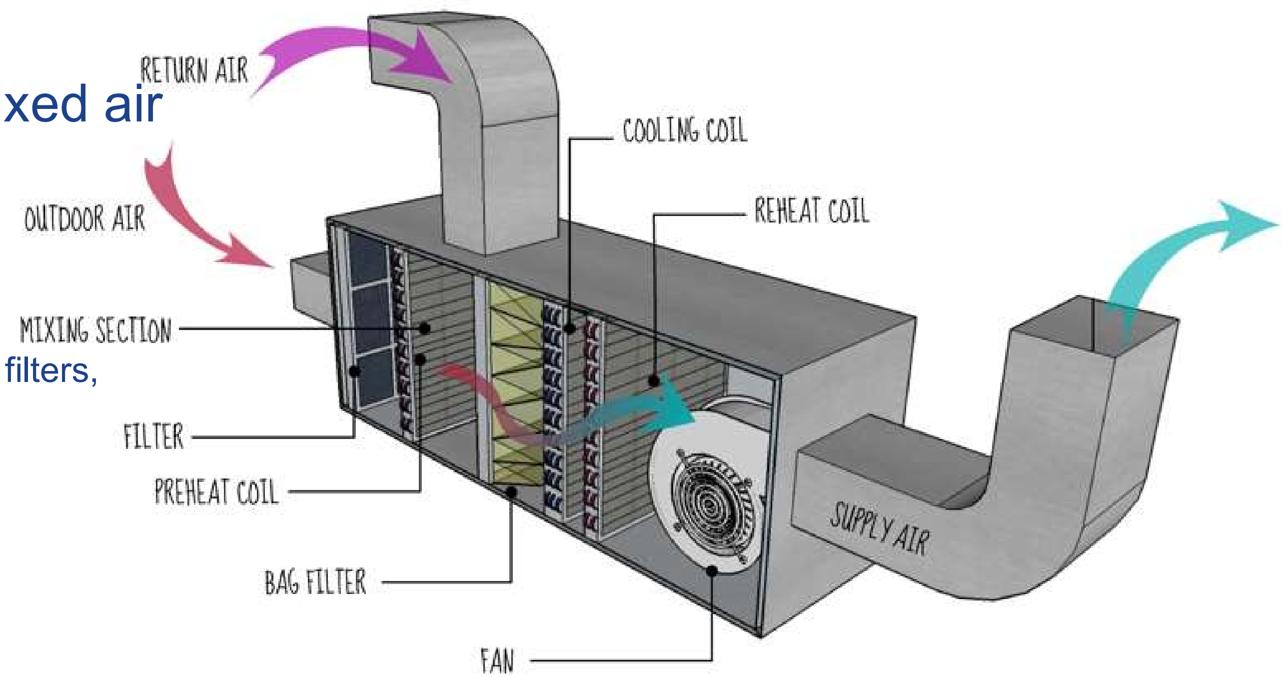
Process Cooling System Components

- **Air side**
  - Air handling units
  - Make-up air units
  - Exhaust fans
- **Water side (Chilled water)**
  - Chillers
  - Cooling towers
  - Pumps



Air Side – Air Handling Units (AHUs)

- Provide cool and dehumidified/humidified mixed air
- Fans
  - Supply fans, return fans (optional)
  - Overcome pressure losses at coils, filters, ductwork
  - VFD
- Dampers
  - Return air dampers
  - Outdoor air dampers



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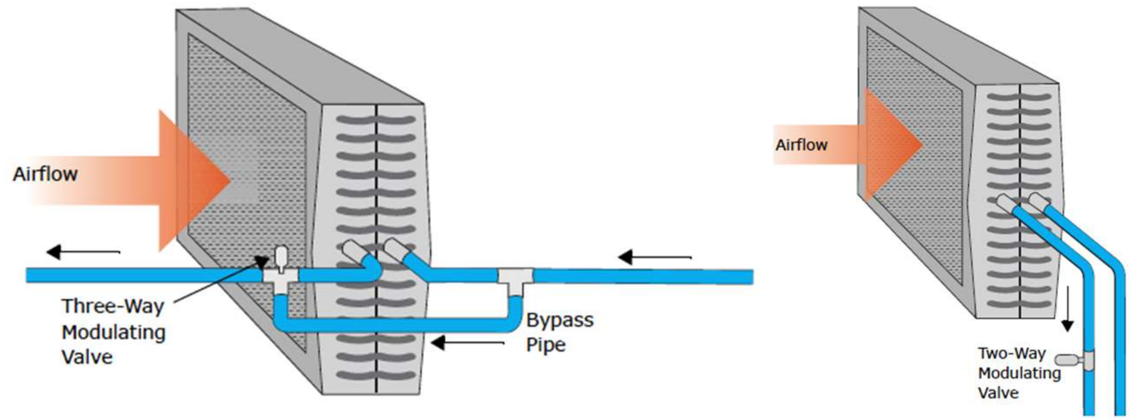
Air Side – AHUs

- Coils
  - Preheat coil (Leaving air temp: 35F–38F)
  - Chilled water coil (Leaving air temp: 42F–45F)
  - Reheat coil (satisfying heat loads)
- Control Valves
  - Preheat coil valve
  - Chilled water valve
  - Reheat coil valve
- Chilled water valve
  - 3-Way
  - 2-Way



Credit: Chiller System Design and Control by Trane

Air Side – AHUs – Filters

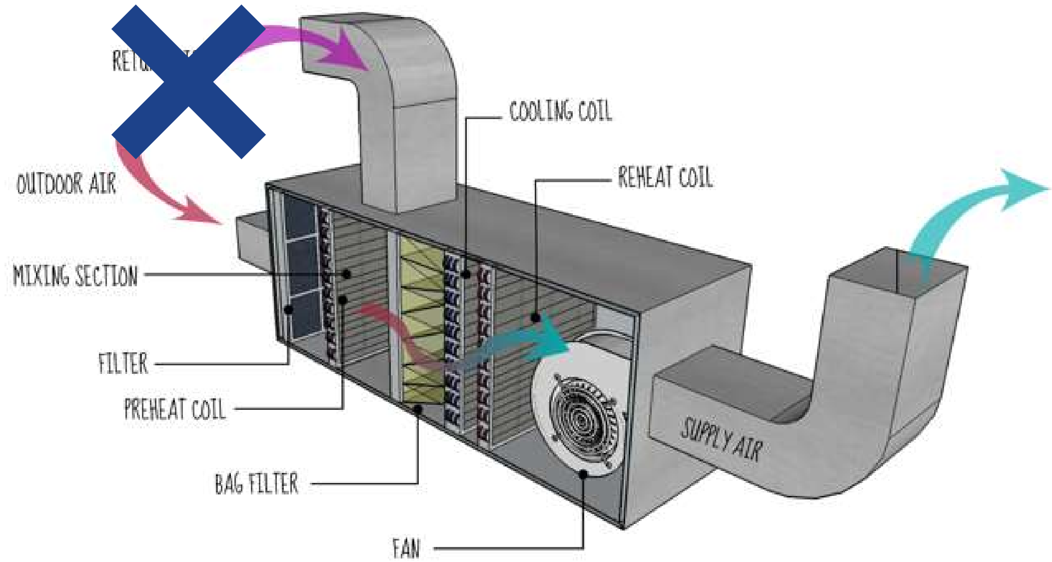
- Measured by Minimum Efficiency Reporting Value (**MERV**) (designed by **ASHRAE** in 1987)
- MERV 1-16
- **Energy**
  - **Higher** MERV #, **higher** pressure drop, **more** fan energy consumption
  - Air purification: no more, no less, just right

MERV VALUE	The filter will trap Average Particle Size Efficiency 0.3 - 1.0 Micron	The filter will trap Average Particle Size Efficiency 1.0 - 3.0 Micron	The filter will trap Average Particle Size Efficiency 3.0 - 10.0 Micron	Types of things these filters will trap
MERV 1	-	-	Less than 20%	Pollen, dust mites, standing dust, spray paint dust, carpet fibers
MERV 2	-	-	Less than 20%	
MERV 3	-	-	Less than 20%	
MERV 4	-	-	Less than 20%	
MERV 5	-	-	20% - 34%	Mold spores, hair spray, fabric protector, cement dust
MERV 6	-	-	35% - 49%	
MERV 7	-	-	50% - 69%	
MERV 8	-	-	70% - 85%	
MERV 9	-	Less than 50%	85% or better	Humidifier dust, lead dust, auto emissions, milled flour
MERV 10	-	50% - 64%	85% or better	
MERV 11	-	65% - 79%	85% or better	
MERV 12	-	80% - 89%	90% or better	
MERV 13	Less than 75%	90% or better	90% or better	Bacteria, most tobacco smoke, proplet Nuceli (sneeze)
MERV 14	75% - 84%	90% or better	90% or better	
MERV 15	85% - 94%	90% or better	90% or better	
MERV 16	95% or better	90% or better	90% or better	

Credit: Filtr.com

Air Side – Make-up Air Units (MAUs)

- Structure is very similar to AHUs
- Provide cooled and dehumidified/humidified 100% outdoor air (OA)
- **Energy**
  - The **more** OA, **more** energy consumption
  - OA quantity: **no more, no less, just right**



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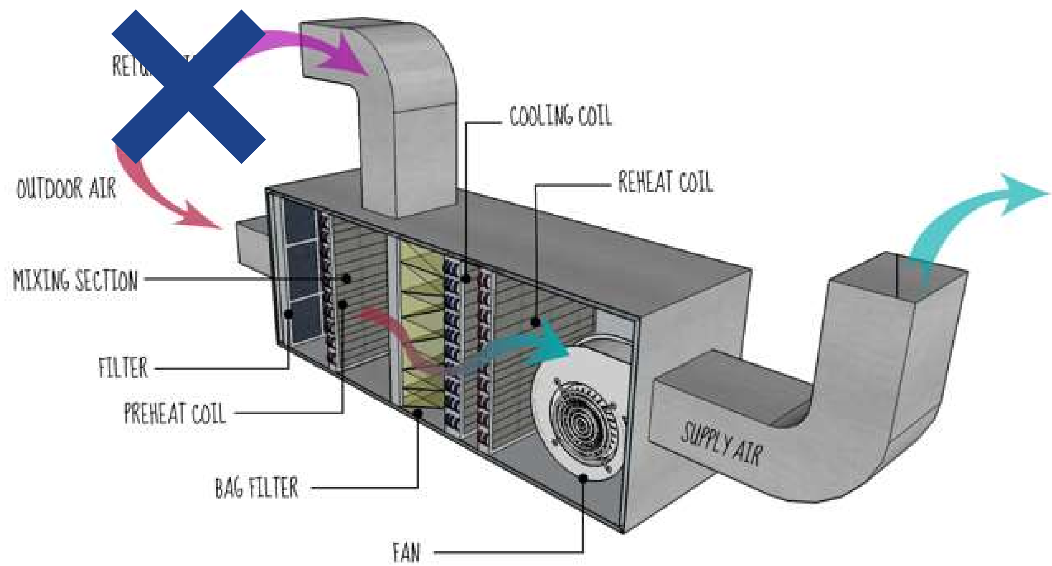
Air Side – Make-up Air Units (MAUs)

Annual Cooling Load of Outdoor Air

City	State	Ventilation Load Index (Ton-hrs/scfm/yr) Latent + Sensible	Total	Cumulative Load Ratio Latent:Sensible
Albuquerque	NM	0.2 + 1.0	1.2	0.2:1
Boston	MA	2.0 + 0.3	2.3	6.4:1
Detroit	MI	2.4 + 0.3	2.7	7.4:1
Minneapolis	MN	2.4 + 0.4	2.8	6.2:1
Pittsburgh	PA	2.5 + 0.4	2.9	5.8:1
New York	NY	2.6 + 0.5	3.1	5.1:1
Chicago	IL	2.6 + 0.5	3.1	5.0:1
Las Vegas	NV	0.2 + 3.7	3.9	0.04:1
Indianapolis	IN	4.0 + 0.6	4.6	6.6:1
Lexington	KY	4.1 + 0.6	4.7	7.4:1
Colorado Spr.	CO	0.6 + 4.2	4.8	0.1:1
Omaha	NE	4.0 + 0.8	4.8	5.3:1
Phoenix	AZ	1.3 + 5.0	6.2	0.3:1
St. Louis	MO	5.3 + 1.1	6.4	4.7:1
Oklahoma City	OK	5.0 + 1.6	6.6	3.2:1
Richmond	VA	5.9 + 0.8	6.7	7.2:1
Raleigh	NC	6.0 + 0.9	6.9	6.8:1
Atlanta	GA	6.2 + 0.9	6.9	6.7:1
Nashville	TN	6.2 + 1.4	7.6	4.6:1
Little Rock	AK	7.3 + 1.6	8.8	4.7:1
Charleston	SC	9.0 + 1.2	10.3	7.3:1
San Antonio	TX	10.4 + 2.4	12.8	4.4:1
New Orleans	LA	12.3 + 1.8	14.1	6.8:1
Miami	FL	17.8 + 2.7	20.5	6.7:1



Credit: Lewis G. Harriman III, etc.

https://i.pinimg.com

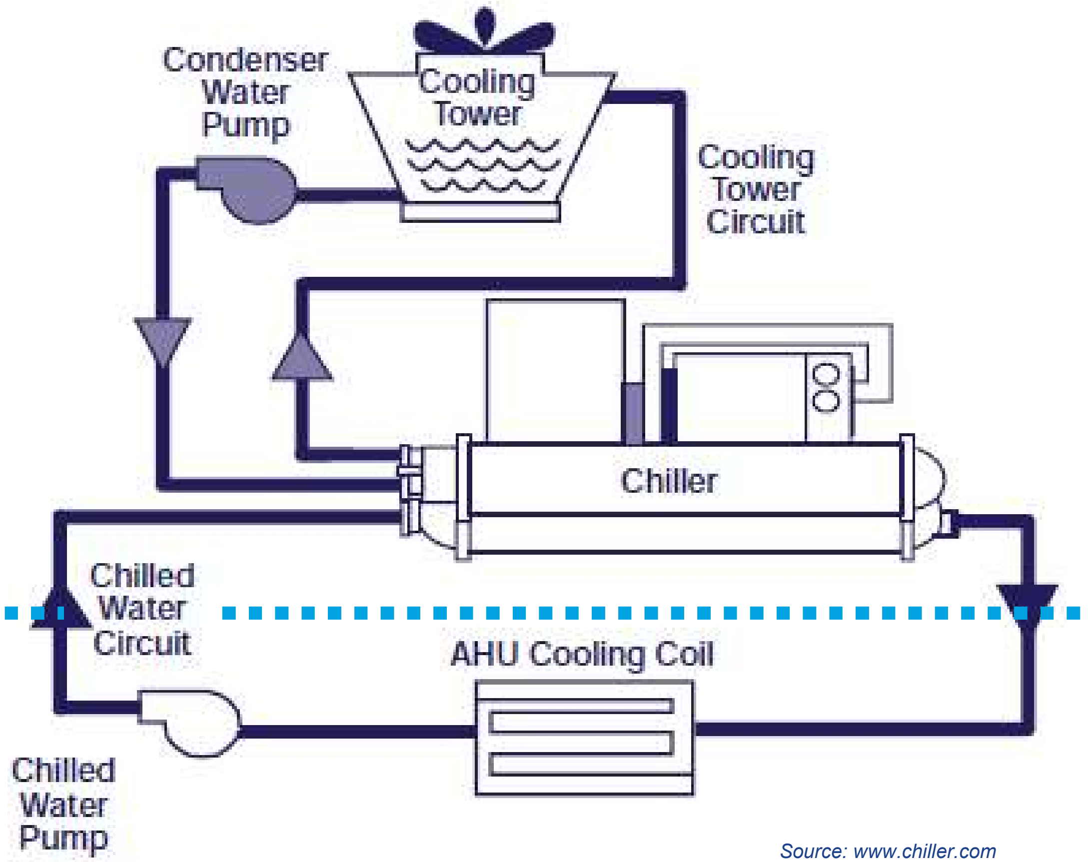
Air Side – Exhaust Fans

- Purpose
  - Exhaust indoor air to **maintain indoor pressure**
  - Exhaust hot indoor air to **maintain space temperature**
- Controls
  - **Manual** on/off
  - **Automatic** based on temperature
  - **Automatic** based on the status of make-up air units
- **Energy**
  - **$500/HP-yr** (given $0.1/kWh; 90% load factor)

www.kamfri.com

Water Side

- **Generation**
  - Chillers
  - Cooling towers
  - Chilled water primary pumps
  - Condensing water pumps
- **Distribution**
  - Chilled water secondary pumps
  - Piping network



Source: www.chiller.com

Water Side – Chillers and Chilled Water Pumps

- Chiller
  - Provide CHW at **desired temperature**
  - Working principle**: vapor compression or absorption** cycle
  - Three efficiency driving factors
    - **Condensing water temperature**
    - **CHW temperature**
    - **Part load ratio**
  - **Metric of efficiency: kW/ton**
- Primary pump
  - **Circulate** CHW through evaporator

Credit: Trane

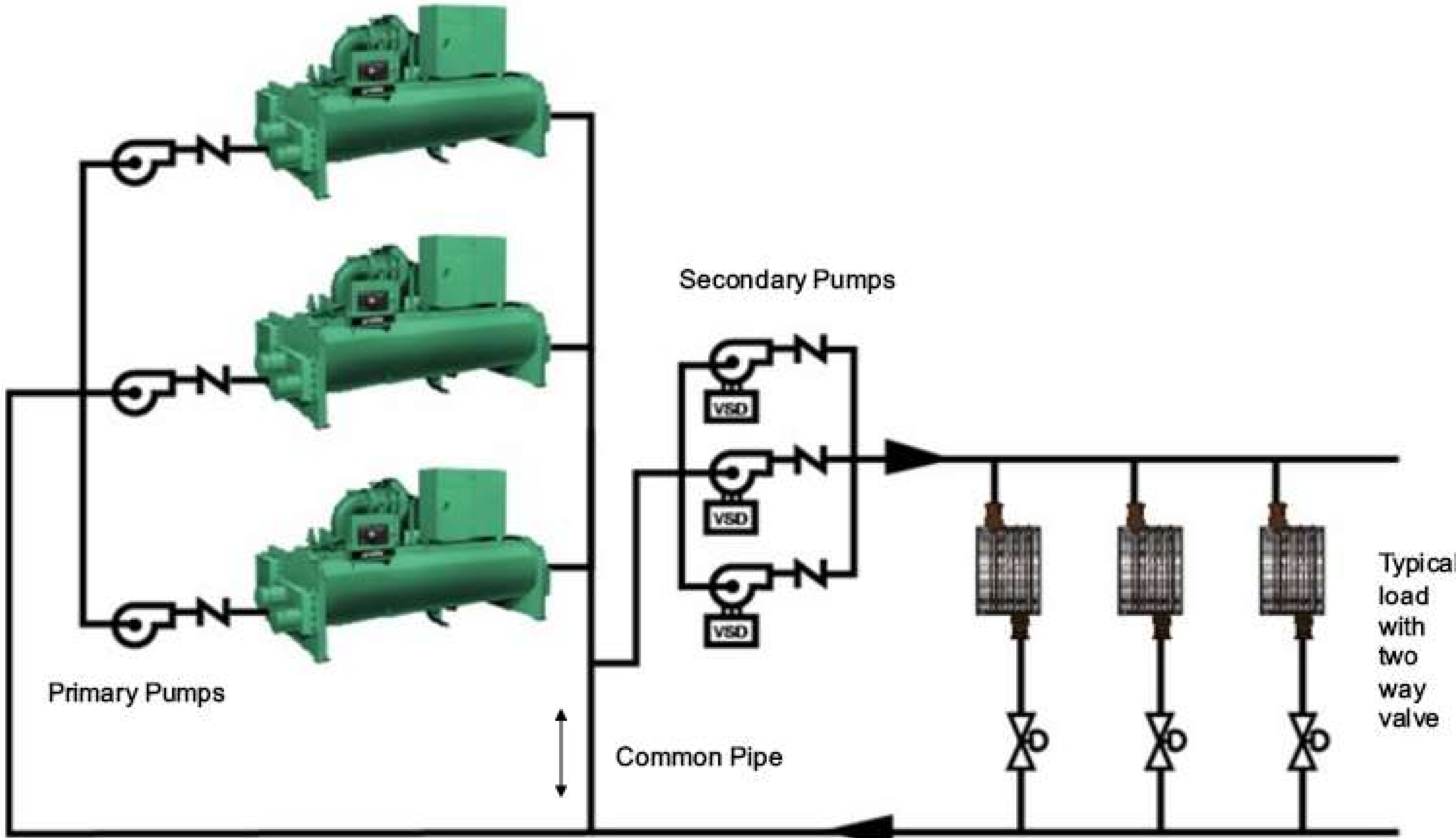
Water Side – Condensing Water Side Overview

- Cooling tower
  - Cool condensing water to **desired temperature**
  - Working principle: **water evaporation**
  - Three efficiency driving factors
    - **Outdoor air wet-bulb temp.**
    - Draft **air flow rate**
    - **Design** of cooling towers
  - Metric of energy efficiency: **gpm/hp**
- Condenser pump
  - **Circulate** condensing water

Credit: Baltimore Aircoil Company

Chilled Water Primary/Secondary Configuration

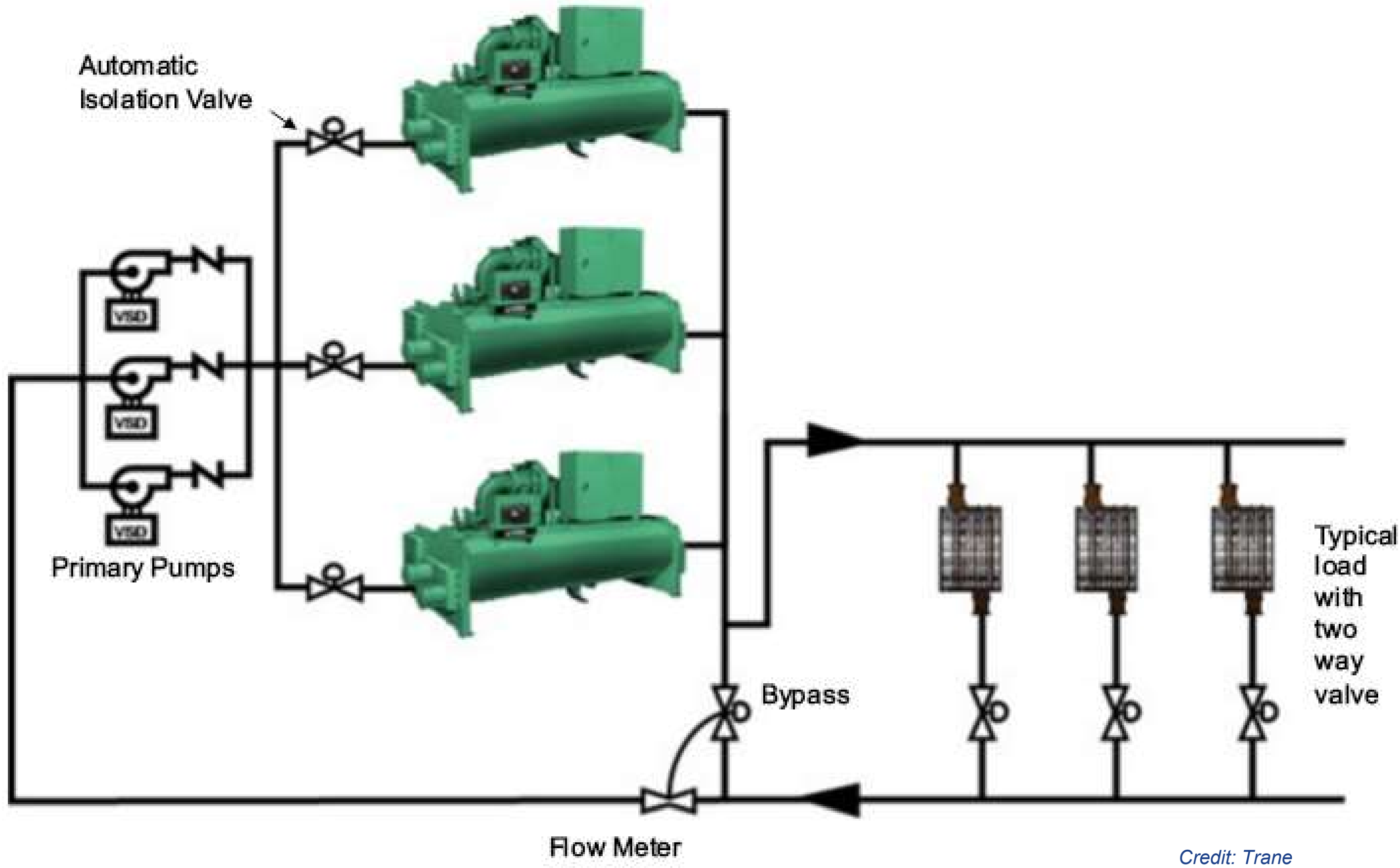
- The **common pipe** is to handle the flow difference between **secondary** and **primary loops**.



Credit: Trane

Chilled Water Primary-only Configuration with VFD

- The **bypass pipe** is to handle the flow difference between the **secondary loop** and **chiller minimum flow rate (typically 20%)**.



Credit: Trane

Energy Conservation Measures

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ENERGY

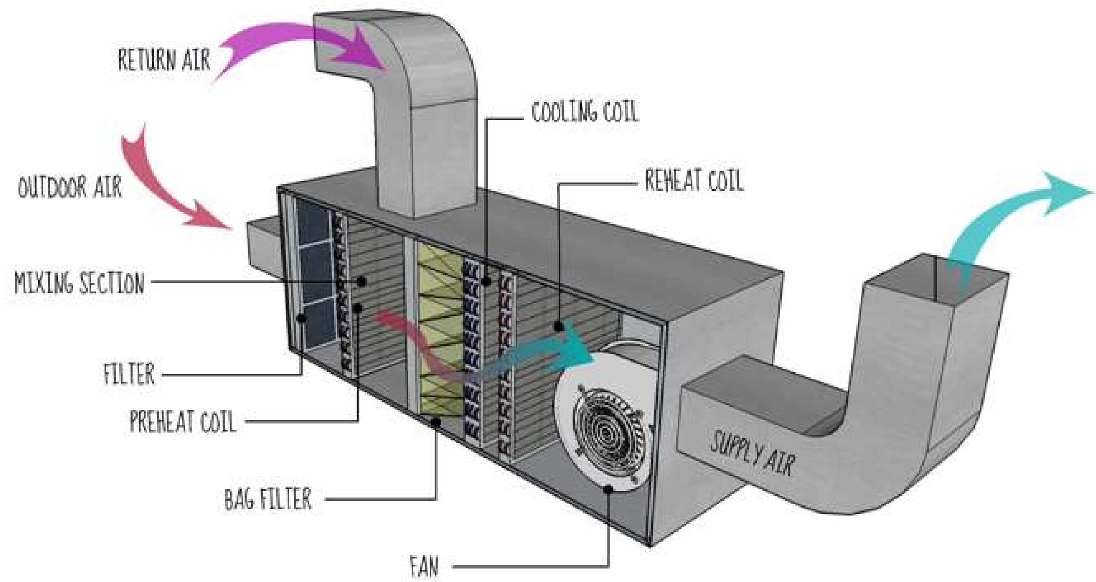
Energy Conservation Measures – Reduce Cooling Loads

- Piping **insulation**
- **Remove heat sources** away from cooled areas/systems
- **Isolate cooled space** from other spaces

Source: Fraser Engineering

Energy Conservation Measures – AHUs and MAUs

- **Turn off** during plant shutdowns
  - Weekends
  - Off shifts
- **Reset space/process setpoint**
  - Avoid cooling/dehumidifying spaces/process when not needed
- **Avoid over-ventilate the space**
- Filters
  - Avoid **over-filter** air
  - Replace filters regularly based on pressure drop



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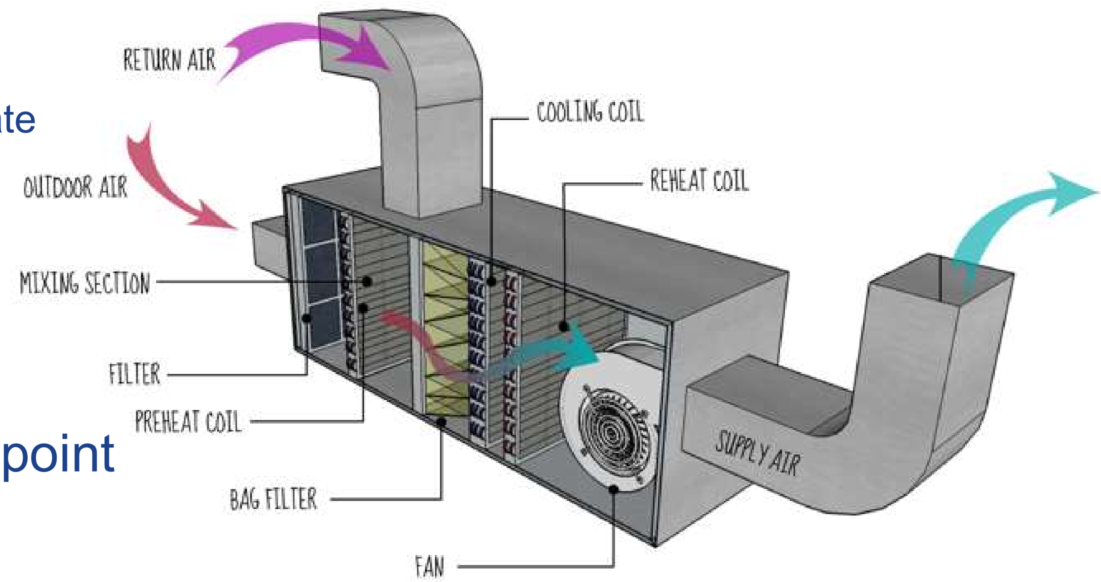
Energy Conservation Measures – AHUs and MAUs

- Install **VFD** to supply fans
  - Vary fan speed based on static pressure set point
  - Provide no more than needed air flow rate
- **Proper controls** of preheat coil
  - Appropriate temp. setpoints
  - Examine preheat coil valve regularly
- **Reset** supply air temperature setpoint
  - Reset based on OAT
  - Avoid overcooling of the space
  - Reduce reheat energy at the space



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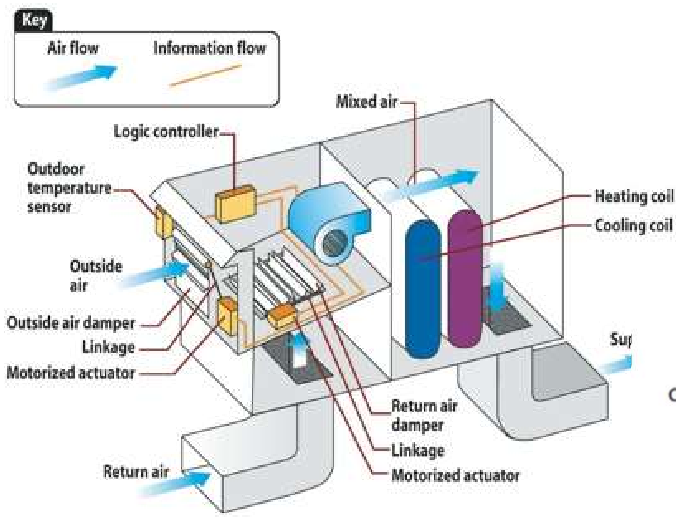
Energy Conservation Measures – AHUs and MAUs

- **Air Economizers**
- **Energy Recovery Units (ERUs)**
  - Enthalpy wheels
  - Heat pipes
  - Coil energy recovery loops



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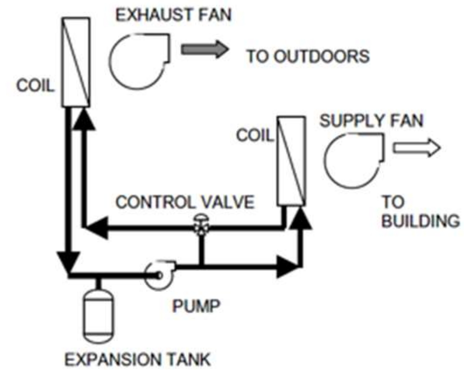
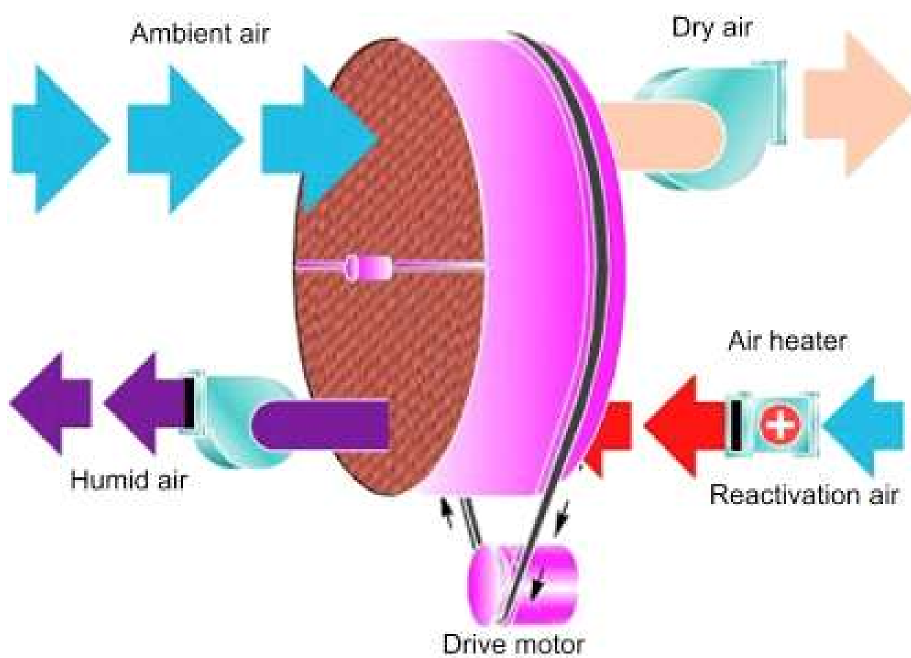


Credit: Carrier

Energy Conservation Measures – Dehumidification

- For low Dew Point requirements, install desiccant wheels
  - Saves energy by not using over-cooled chilled water and supply air
  - Can achieve very low dew point with moderately cold chilled water (beneficial for chillers' energy efficiency)
- Typically used in some clean room applications
- Things to keep in mind
  - Avoid over-dehumidification
  - Consider desiccant wheels instead of dedicated very-low temperature glycol system

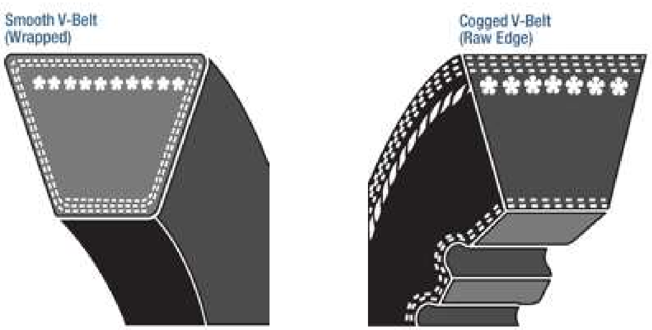


Credit: B.Purushothama

Energy Conservation Measures – Exhaust Fans

- Energy
  - $500/HP-yr (given $0.1/kWh; 90% load factor)
- Turn off during plant shutdowns
  - Weekends
  - Between shifts
- Controls
  - Automatic based on temperature
  - Automatic based on the status of make-up air units
- Drive belt
  - Replace standard V-belt with cogged V-belt (**~2% more efficient**)

www.kamfri.com

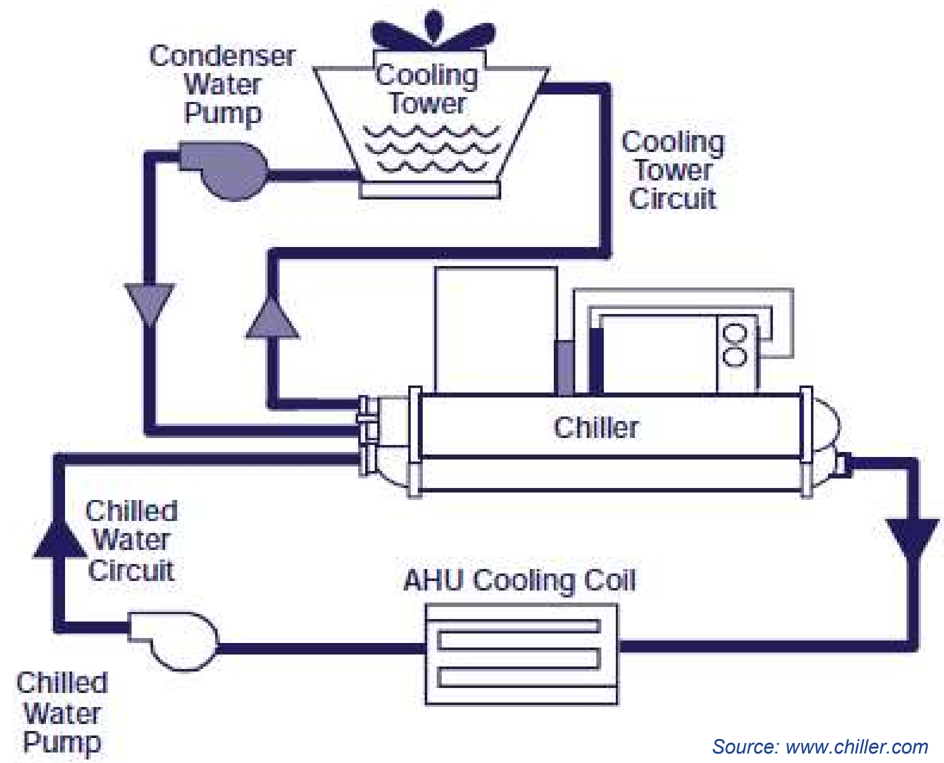


Credit: Baart Industrial Group

Challenges Optimizing Chilled Water System Efficiency

No Settings can make all components happy simultaneously!

- Colder CHW
  - **More** chiller energy
  - **Less** distribution pump energy
- Cooler condensing water
  - **More** cooling tower fan energy
  - **Less** chiller energy
- Less condensing water flow
  - **Less** condenser pump energy
  - **More** cooling tower fan energy



Source: www.chiller.com

Energy Conservation Measures – Chiller and CHW Pumps

- CHW supply temperature setpoint
  - Reset based Outdoor Air (OA) Dry Bulb (DB)
  - OA DB = 70 F, CHW = 42 F
  - OA DB = 50 F, CHW = 46 F
- Chiller
  - Select VFD chillers
  - Magnetic bearings (Lower turn down ratio)
- Primary pump
  - Convert to a **primary-only system**
  - **Remove** triple-duty valves

Credit: Trane

Credit: Thermal Engineering Group

Energy Conservation Measures – Cooling Towers and CW Pumps

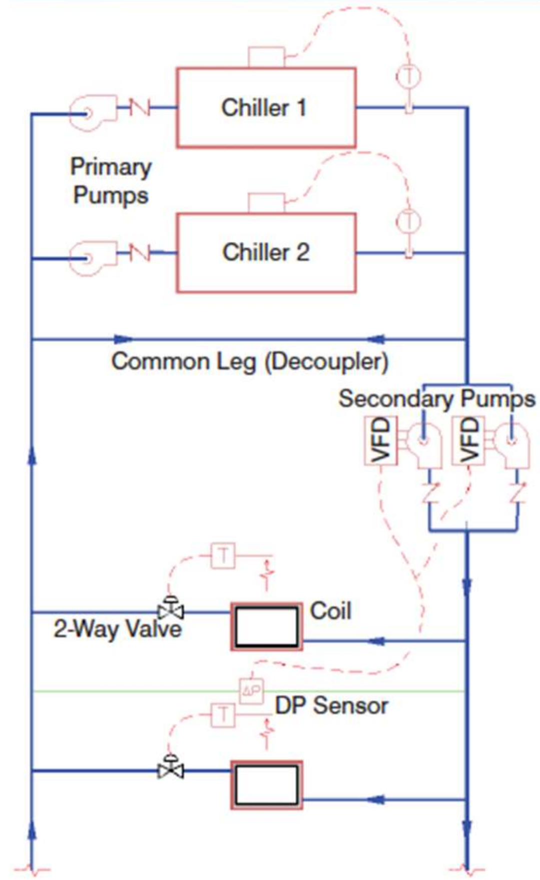
- CW supply temp. set point
  - Reset based on Outdoor Air **Wet Bulb (WB)**
  - OA WB = 68 F, CW = 75 F
  - OA WB = 47 F, CW = 60 F
- Cooling tower fan
  - Install VFD (typically **6:1** Turndown)
- Condenser pump (Be cautious!)
  - Install VFD (typically **2:1** Turndown)
  - Modulate pump speed to maintain 12 F range (Condensing Water DelT)
  - ***Check with operation manual before implementation***

Credit: Baltimore Aircoil Company

Credit: Sitespan

Energy Conservation Measures – Distribution System

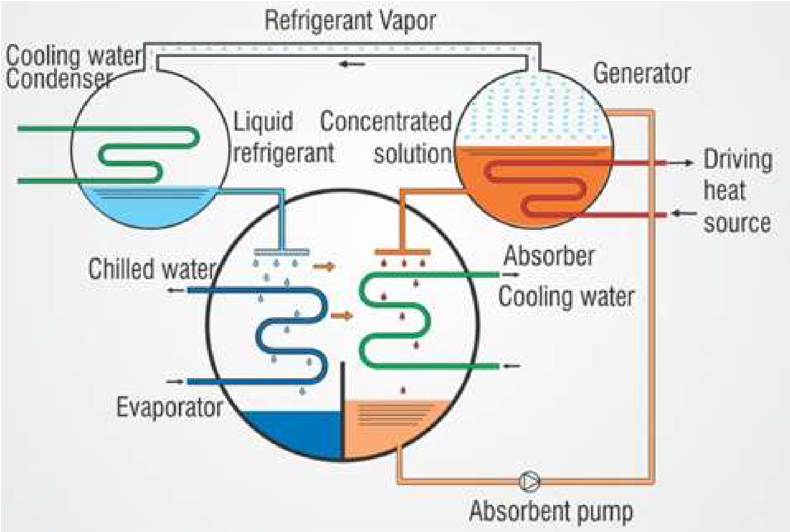
- Distribution/Secondary Pumps
  - Install **VFD**
  - **Differential pressure setpoint reset** based on **most-open valve** position
- Piping
  - **Change** 3-way cooling coil control valves to 2-way valves
  - **Remove** triple-duty valves (balancing, check valve and shutoff valve)
  - Identify **bottle necks**
  - **Loop** piping network, so loads can be satisfied from both directions
  - Consider **tertiary (booster) pumps for very remote loads**



Credit: Steven T. Taylor

Technologies – Absorption Chiller

- Only effective when there is a viable waste heat source that would otherwise be rejected

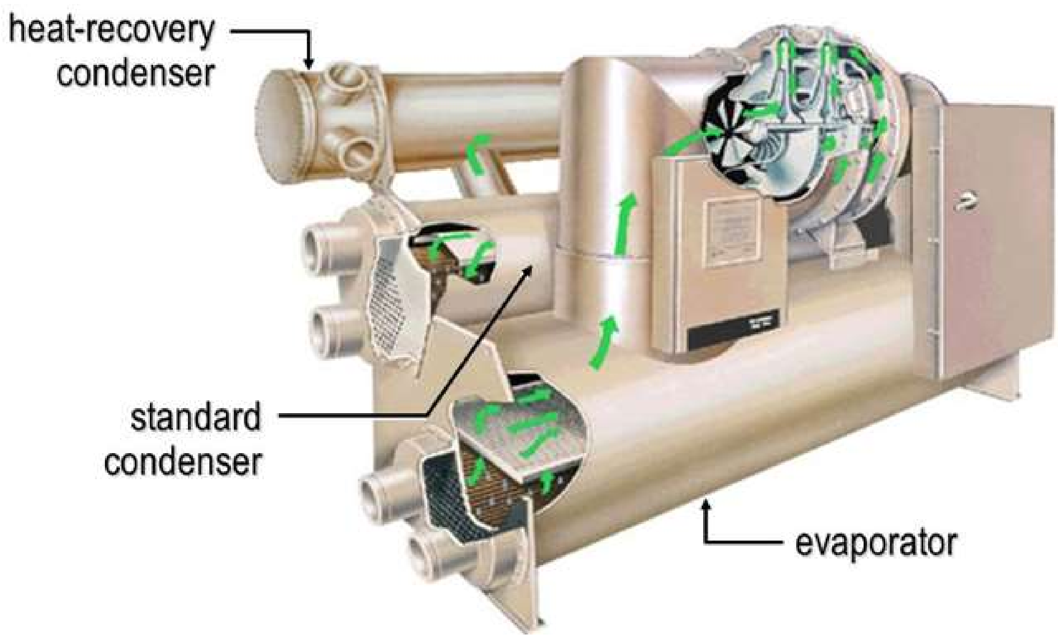


Credit: Thermax

Credit: Hitachi

Technologies – Heat Pump (or Heat Recovery) Chiller

- Recovering (not rejecting) condenser heat to supplement space/process heating
- Economic benefit largely dependents on NG vs electricity rates

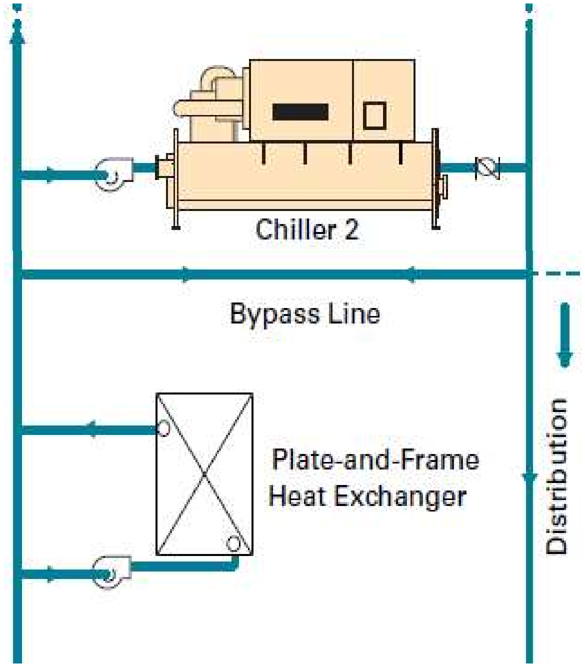


Credit: Trane

Technologies – CHW System w/ Free Cooling

- Water-side economizer (Plate and Frame Heat Exchanger)
- Some chillers are starting to have this feature built-in

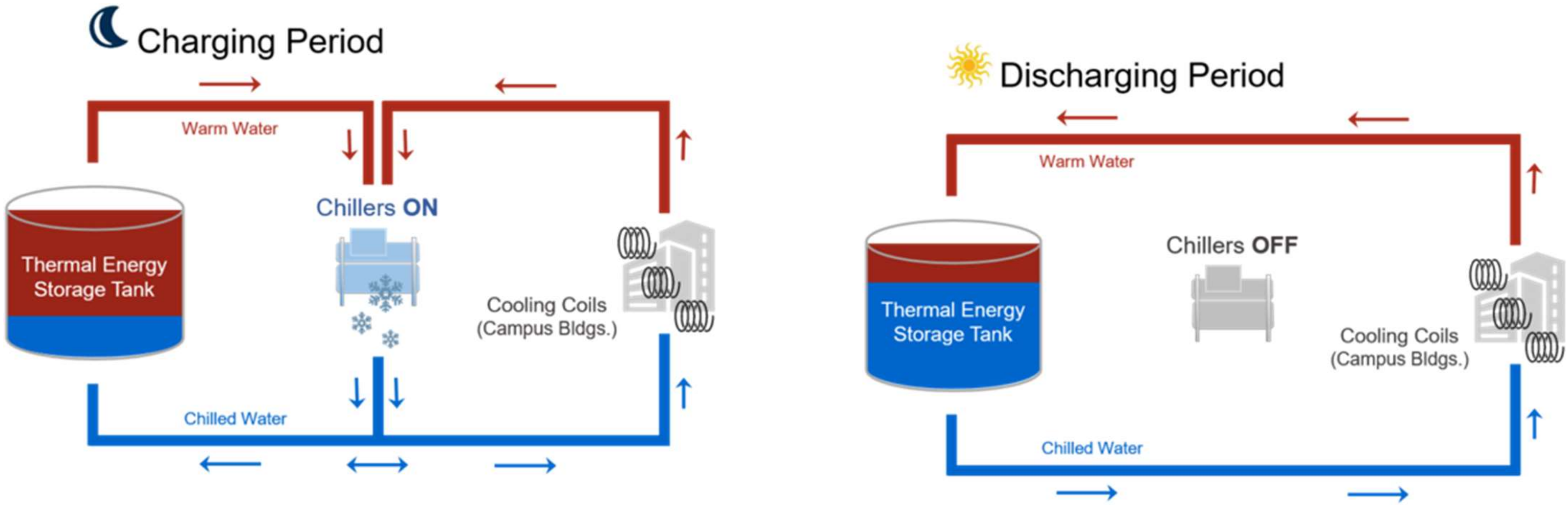
Source: Plate Concepts



Source: Chiller System Design and Control by Trane

Technologies – Thermal Storage

- Cooling tower more efficient at night
- Avoid peak electricity use



Source: The University of Texas at Austin

Measurements

- Ports
  - **Pressure-temperature ports**
- Temperature
  - Temperature probe
- Differential pressure
  - Hydronic manometer
  - Fittings
- Flow rate
  - **Ultrasonic flow meter**
  - Hydronic manometer and math

Top 5 Energy Conservation Measures for Air Side

1. **Turn off** AHUs, MAUs, and exhaust fans during plant shutdowns
2. **Reset** control temperature set points for AHUs
3. **Regularly replace** filters
4. **Avoid overventilation** to save energy for MAUs
5. Upgrade exhaust fan controls to **automatic**

Credit: Nortek

Credit: Safe Grain

Top 5 Energy Conservation Measures for Water Side

1. Convert chilled water systems from constant to variable flow by **replacing 3-way with 2-way control valves** and installing **VFDs** on secondary pumps
2. Convert cooling tower fans from **1- or 2-speed to variable speed** by installing VFDs
3. **Reset chilled water supply temperature setpoint** based on the process load/OAT
4. **Reset condensing water entering-temperature setpoint** based on the ambient wet bulb temperature
5. Convert condensing water systems from **constant to variable flow** by installing VFDs on condensing water pumps

Rules of Thumb and Unit Conversions

- 1°F increase of chilled water temperature improves the chiller efficiency by ~1.5%; 1°F decrease of condensing water temperature improves the chiller efficiency by ~1.5%
- Pump sizing: 2.0 – 2.4 GPM/ton for chilled water and 2.5 – 3.0 GPM/ton for condensing water
- Distribution pipe sizing: 10 ft/s water velocity or 4 ft w.c. pressure loss per 100 ft
- kW/ton = 12/EER; EER = COP × 3.413; kW/ton = 12/(COP × 3.413)
- 1 refrigeration ton = 12,000 Btu/hr
- 1 cooling tower ton = 15,000 Btu/hr

DOE Technical Resources

U.S. DEPARTMENT OF ENERGY

Resources, Tools, and Training Opportunities

1. Better Plants Energy Treasure Hunts Info Cards
2. Better Plants Energy Treasure Hunts Cheat Sheets
3. Excel Tools
4. Better Plants In-Plant Training Calendar
5. MEASUR Tool Suite

MEASUR – Psychrometric Calculator

PSYCHROMETRIC CALCULATOR

Dry Bulb Temp (T_{DB})	90	°F
Humidity Metric	Wet Bulb Temperature	
Wet Bulb Temp (T_{WB})	85	°F
Barometric Pressure (P_{atm})	26.57	in Hg

Calculate From Altitude

Create Row

T_{DB} °F	RH %	T_{WB} °F	T_{DP} °F	h btu/lb	
90	38.65	70	61.5	36.7	Delete
90	51.55	75	69.8	41.7	Delete
90	65.96	80	77.1	47.3	Delete
90	82.04	85	83.8	53.7	Delete

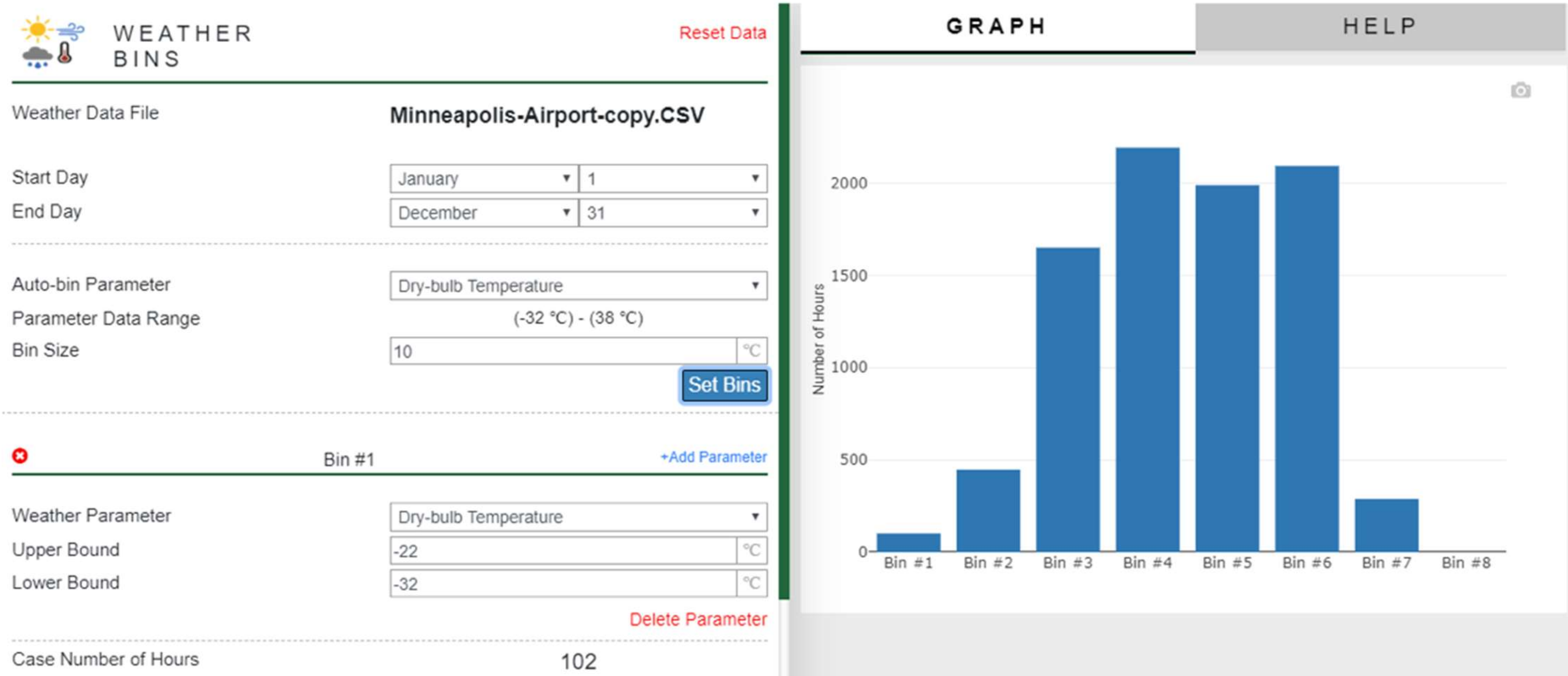
Copy Table

RESULTS HELP

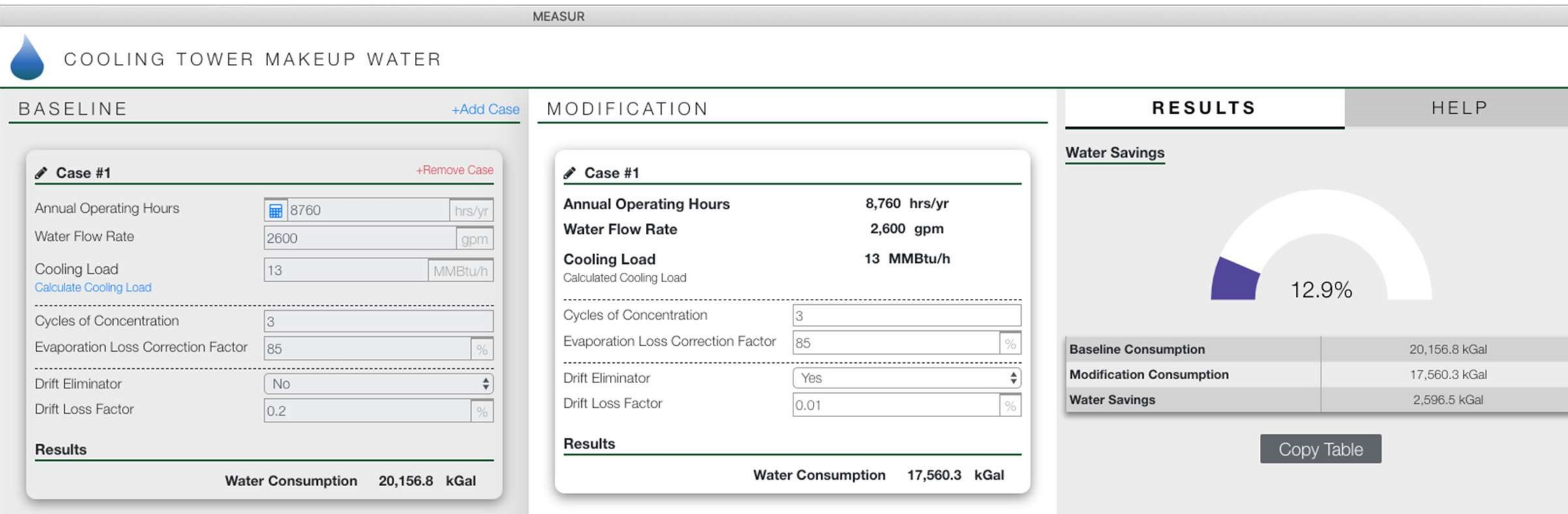
Psychrometric Data

Dry Bulb (°F)	90
Relative Humidity (%)	82
Wet Bulb (°F)	85
Dew Point (°F)	83.8
Enthalpy (btu/lb)	53.7
Air Density (lb/ft³)	0.06301
Specific Volume (ft³/lb)	16.32
Barometric Pressure (in Hg)	26.57
Saturation Pressure (in Hg)	1.423
Saturated Humidity Ratio	0.035
Absolute Pressure (in H_2O)	26.57
Degree of Saturation	0.812
Humidity Ratio	0.0286

MEASUR – Weather Binning Calculator



MEASUR – Cooling Tower Make-up Water Calculator



Q & A

Submit Questions
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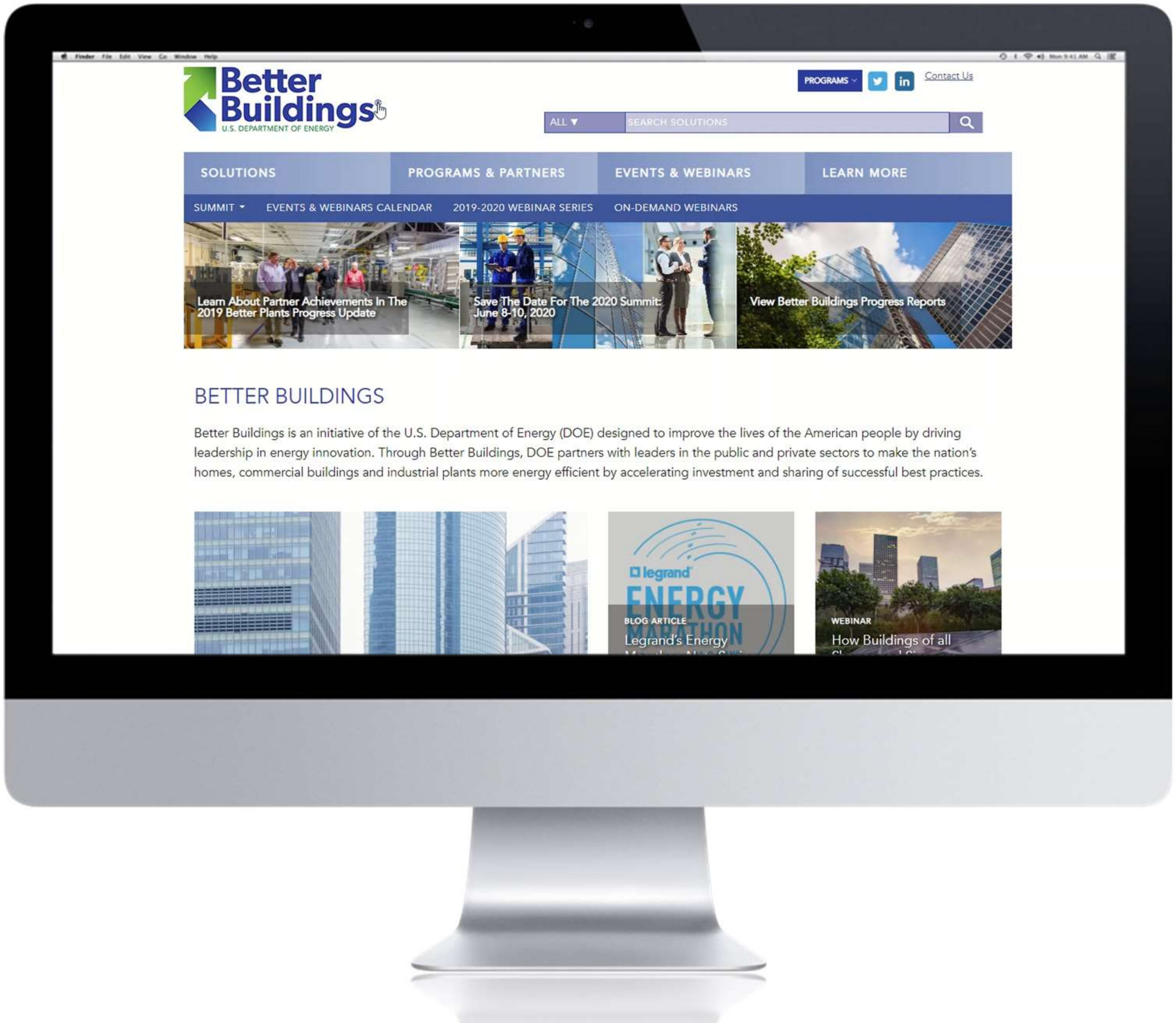

Better Buildings
U.S. DEPARTMENT OF ENERGY

Better Plants Online Learning Series

ENERGY TREASURE HUNTS WITH EPA

Thr, Aug 20, 2020 | 1:00 - 2:00 PM ET

PUMPS AND FANS

Thr, Aug 27, 2020 | 1:00 - 2:30 PM ET

PROCESS HEATING & WASTE HEAT REDUCTION

Thr, Sep 3, 2020 | 1:00 - 2:30 PM ET

FIELD VALIDATION

Thr, Sep 10, 2020 | 1:00 - 2:00 PM ET

ENERGY MANAGEMENT DURING A PANDEMIC

Thr, Sep 17, 2020 | 1:00 - 2:00 PM ET

MEASUR TOOL SUITE

Thr, Sep 24, 2020 | 1:00 - 2:00 PM ET

PROCESS COOLING

Thr, Oct 1, 2020 | 1:00 - 2:00 PM ET

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Additional Questions?

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